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Ruth Meinzen-Dick

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## Private Tubewell Development and Groundwater Markets in Pakistan: A District-level Analysis\*

RUTH MEINZEN-DICK

### INTRODUCTION

Groundwater irrigation, which was developed in the 1960s to increase vertical drainage to prevent waterlogging and salinisation in canal commands, has now become a major component of the overall irrigation sector in Pakistan. An estimated 37 percent of total irrigation supplies at the farm gate comes from groundwater [NESPAK (1991)].

Along with the shift in purpose for groundwater development from providing drainage to providing irrigation supplies, has come a shift from public to private tubewells as the primary source of groundwater in Pakistan. The increase in private tubewells has not only increased the total availability of water for crop production, but also provided farmers with greater control over irrigation supplies. Because groundwater from private tubewells is generally not tied to the rigid *warabandi* schedule of canal deliveries, water applications can be more closely matched to crop requirements. The result is higher yields and higher economic returns to irrigated agriculture [Meinzen-Dick and Sullins (1993); Shah (1993)]. However, the number of private tubewells is still limited. In 1991 there were approximately 286,300 private tubewells, with only 6 percent of farmers owning tubewells [Government of Pakistan (1991)].

Informal markets for private tubewell water provide an important means of increasing access to groundwater resources among non-tubewell owners. By expanding access to groundwater, water markets can increase equity as well as productivity of irrigation. The activity of such groundwater markets has been

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Ruth Meinzen-Dick is Research Fellow, International Food Policy Research Institute, Washington, D.C., USA.

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examined in studies by Renfro (1982); WAPDA (1990); Meinzen-Dick (1993); Meinzen-Dick and Sullins (1993); Strosser and Kuper (1994) and Strosser and Meinzen-Dick (1993). However, the degree of activity of water markets (in terms of percent of tubewell owners participating and amount or percent of groundwater sold) is highly variable, making it difficult to generalise about water markets based on micro-level field studies in a limited number of sites.

There is increasing interest in water markets as a means to increase equity in the use of groundwater and overall productivity of irrigated agriculture [ICWE (1992)]. However, in order to formulate policies to stimulate water market development, we need better understanding of the factors which affect their development. This paper uses a conceptual framework to identify factors which affect tubewell density and groundwater markets, and applying this framework to district-level data for all of Punjab, NWFP and Sindh.

Data for this study are drawn from published sources, particularly a 1991 study by NESPAK. The NESPAK study conducted a survey of tubewell owners, along with compiling statistics on the number of tubewells, surface and groundwater hydrology, water quality, energy usage, and other parameters. In addition to the NESPAK data, the present study draws on district-level development statistics for data on canal irrigated area, farm characteristics, rural development, and agricultural production.<sup>1</sup>

## CONCEPTUAL FRAMEWORK

The factors affecting private tubewell development and the emergence of groundwater markets are complex and interlinked, involving physical, economic, and social forces. Figure 1 shows a conceptual framework based on Strosser and Meinzen-Dick (1993) for identifying relationships between groundwater markets and the environment in which they operate. The broad categories of physical environment, farm characteristics, surface irrigation, rural development, and agricultural production are used to identify and classify key factors affecting both groundwater supply through private tubewells and the activity of groundwater markets. Although groundwater supply and water markets can also have an impact

<sup>1</sup>Although many development statistics are available in time series at the district level, the NESPAK study is the only source of many key variables on the environment and activity of water markets. Because that is available for one period only (1990), this study is limited to cross-sectional analysis. Balochistan was excluded from the analysis because data on many variables were not available. However, this is not expected to distort the analysis to any great extent because Balochistan accounts for a low proportion of the groundwater resources, tubewells, and groundwater markets in the country.

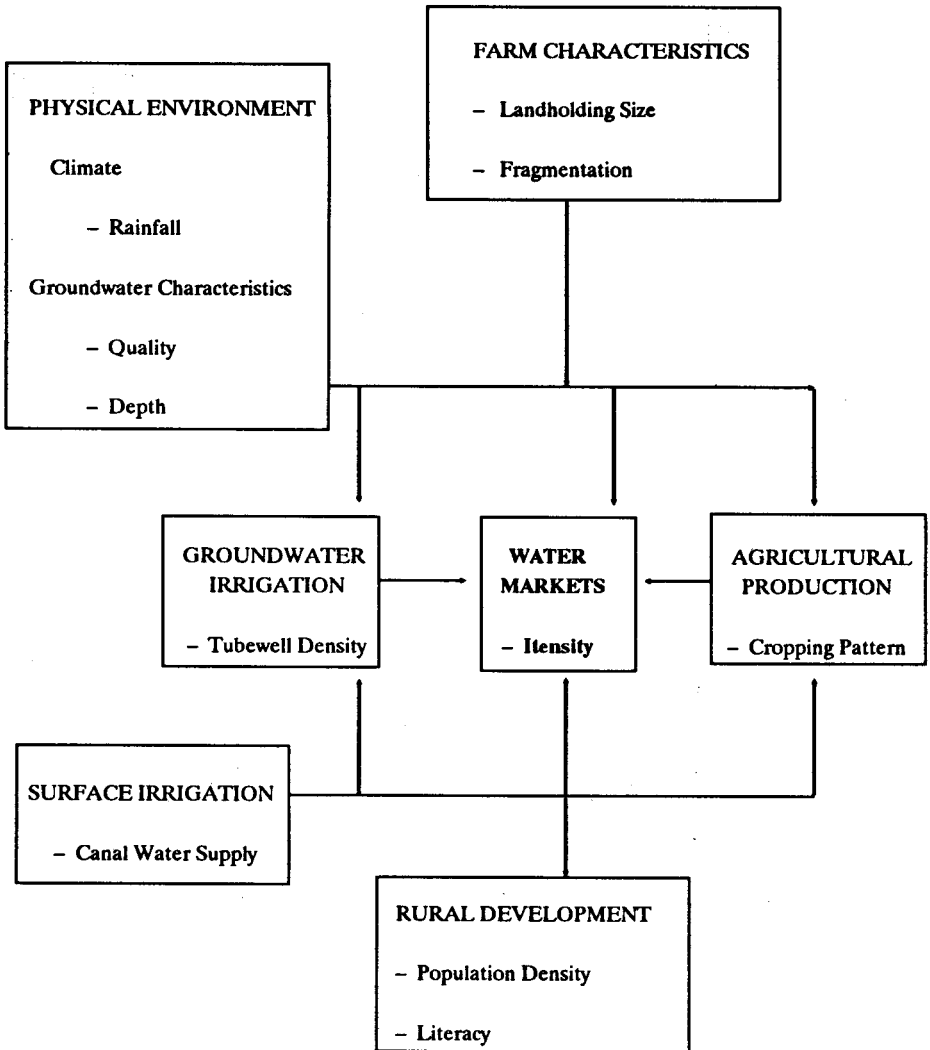


Fig. 1. Factors Affecting Groundwater Irrigation and Water Markets.

on each of these factors, such feedback mechanisms are less direct, and are not included in the present analysis.

Prior empirical studies of water market development have not addressed the complete set of factors affecting water market development for three reasons. First, the studies have not been guided by a comprehensive model that takes into account the interactions between the physical and social environments, conjunctive use of surface and groundwater, and agricultural production, such as this framework sets out. Second, micro-level field studies often cannot capture variability in key parameters. The district-level analysis in this paper covers a broader area and can capture more of this variability (although it sacrifices some of the accuracy of micro-level data by aggregating over all farms in a district). Finally, it is difficult to obtain accurate data on all relevant factors impinging on private tubewell and water market development. The present study goes beyond previous work on water markets, but still does not provide a fully comprehensive analysis, particularly of the interrelationships between factors.

### **Physical Environment**

The physical environment plays a key role in determining agronomic potential of an area and demand for irrigation:

Better agroclimatic opportunities such as better rainfall, a higher moisture holding capacity of the soil and a better irrigation potential . . . increase the economic return to private farm investments such as tractors, draft animals or pumpsets [Binswanger, Khandker and Rosenzweig (1989), p. 5].

Climate affects the need for irrigation to meet crop requirements. Although temperature, solar radiation, and wind all affect evapotranspiration, rainfall is often the single most important determinant of irrigation demand, and is therefore used in this study.

Groundwater characteristics, particularly water table depth and water quality, affect both the costs and returns to use of groundwater for irrigation. Tubewell use may, in turn affect groundwater characteristics, with extensive pumping lowering the water table and potentially altering the water quality. However, recharge from surface irrigation is a larger factor in determining groundwater characteristics in most areas.

### **Surface Irrigation**

Studies of irrigation in Pakistan need to take into account the conjunctive

nature of surface and groundwater irrigation. Although most canal systems are under government control while most tubewells are operated by farmers, use of groundwater from private tubewells cannot be understood apart from the operation of the surface system. The availability of canal irrigation has both direct and indirect impacts on groundwater irrigation. Canal supplies provide a cheaper alternative to tubewells as a source of irrigation, thereby reducing demand for groundwater irrigation. At the same time, canal water provides recharge to the water table, making groundwater more available for irrigation. In a more qualitative sense, unreliable canal deliveries can increase demand for tubewell water, while excessive canal supplies can cause waterlogging and reduce the agronomic potential of an area.

### **Farm Characteristics**

Tubewells are lumpy investments. In the absence of highly affective credit markets, larger farmers are more likely to be able to purchase tubewells because they can more readily mobilise the financial resources for tubewell investment. Large farmers are also likely to use more of the water on their own land than are small and medium farmers, and have less surplus water to sell. Thus, the percentage of tubewell owners is likely to be higher with large holding sizes, but the activity of water markets may be greater where medium and small farmers predominate. Fragmentation of holdings also reduces the proportion of a farm that can be served by a tubewell, and is therefore likely to have a negative effect on tubewell ownership, but increase the availability of and demand for tubewell water sales.

### **Rural Development**

Both technology adoption and market development are associated with broader rural development trends. As population density increases, so do pressures for agricultural intensification, including irrigation development. Increases in education and literacy rates facilitate the adoption of new technology such as private tubewells.

### **Agricultural Production**

The effect of groundwater irrigation and water markets on agricultural production has established in several studies [e.g. Freeman Lowdermilk and Early (1978); Renfro (1982); WAPDA (1990); Meinzen-Dick (1993)]. However, agricultural production also has an impact on groundwater development and water

markets. Cropping patterns with crops that are highly water-consumptive and sensitive to moisture stress tend to increase demand for irrigation, including groundwater, while cultivation of profitable crops is needed to make tubewell investment and groundwater purchases profitable.

The effect of each of these factors—the physical environment, surface irrigation, farm characteristics, rural development, and agricultural production—is likely to be different for the development of private tubewells and activity of water markets. Moreover, the number and density of private tubewells is likely to have an impact on groundwater markets, though whether it will reduce the activity of water markets because more farmers own tubewells, or increase the activity by making groundwater available to more area is an empirical question. The following sections of this paper present results of a two-stage estimation of factors affecting private tubewell density and intensity of water markets, using district-level data.

### INVESTMENT IN PRIVATE TUBEWELLS

Based on the foregoing discussion, a simple model is formulated to explain the density of private tubewells:<sup>2</sup>

$$\begin{aligned}
 \text{TWDENSE} = & 13.240 & - 0.022 \text{ RAIN} & - 0.897 \text{ GWQUAL}^* \\
 & (23.002) & (0.013) & (0.458) \\
 & - 0.738 \text{ DEPTH}_B^{**} & - 8.571 \text{ CANAL} & + 1.044 \text{ FARMSIZE} \\
 & (0.285) & (5.105) & (0.767) \\
 & - 2.813 \text{ FRAGMENT} & + 3.384 \text{ POPDEN}^{**} & + 0.939 \text{ LITERACY}^{**} \\
 & (4.319) & (1.206) & (0.498) \\
 & + 69.472 \text{ RICE}^{**} & - 7.009 \text{ NWFP} & - 11.910 \text{ SINDH}^* \\
 & (21.734) & (9.837) & (6.799)
 \end{aligned}$$

Adjusted R Square = 0.55,      Number of Observations = 30.  
 (Standard Errors in parentheses)

<sup>2</sup>There are no compelling theoretical grounds to choose a particular structural form, so a straightforward linear specification is used.

where:

- TWDENSE** = Tubewell density, defined as number of private tubewells per thousand acres of cultivable area.<sup>3</sup>
- RAIN** = Average annual rainfall, in mm, used instead of rainfall from particular years because groundwater development is a long-term phenomenon. While short-term fluctuations may have an effect on investment in tubewells, total density of tubewells is more likely to be affected by average rainfall.
- GWQUAL** = Groundwater quality, defined as the proportion of area with water of poor quality.
- DEPTH<sub>B</sub>** = Groundwater depth before installation of tubewells, as reported by farmers in the NESPAK survey, to indicate the water table conditions farmers faced when deciding whether to install tubewells.
- CANAL** = Area irrigated by canals, as a percent of potentially cultivable area in the district.
- FARMSIZE** = Average farm size, in acres.
- FRAGMENT** = Average number of fragments per farm.
- POPDEN** = Rural population density per cultivable area.
- LITERACY** = Rural male literacy rate.
- RICE** = Percent of gross sown area under rice. Because rice is very water-consumptive and sensitive to moisture stress, farmers with a high proportion of rice are more likely to invest in tubewells.
- NWFP** = Dummy variable for North West Frontier Province.
- SINDH** = Dummy variable for Sindh Province.

The effect of rainfall on reducing the density of private tubewells is not significant, but both variables relating to groundwater have a significant negative effect in this model. Lower returns to groundwater irrigation are likely when water quality is poor because in the short run saline groundwater use depresses yields, while in the long run using poor quality groundwater has an impact on soil characteristics and the sustainability of agricultural production. Deeper water

<sup>3</sup>Total cultivable area (net sown area plus current fallows plus cultivable waste) was used as denominator instead of cultivated area to reduce endogeneity effects of irrigation increasing the cultivated area in a district.



tables increase the costs of tubewell installation and pumping, and therefore have a significant negative effect on tubewell density.

Greater availability of canal irrigation has a negative effect on tubewell density, though this is not significant. Surface water supplies provide a much cheaper alternative to groundwater, and therefore reduce farmers' investment in tubewells. However, other micro-level studies Freeman, Lowdermilk and Early (1978); Renfro (1982); Strosser and Kuper (1994) have shown that deficiencies in the canal irrigation system provide an impetus for groundwater use. To capture this effect requires more refined indicators of canal deliveries than the simple percentage of cultivable area served by canals (such as total water deliveries and timeliness or reliability of canal supplies), which are not available at the district level.

Average farm size has a positive effect on tubewell density, as would be expected where large landowners are more likely to also own tubewells. However, averaging farm sizes over all farms in the district is an insufficient proxy for the number of large farmers, and thus this coefficient is not significant. The average number of fragments is negatively related to tubewell density, because if land is held in multiple parcels it is more difficult to irrigate the farm from one tubewell.

Population density has a strong positive effect on tubewell density, consistent with the induced innovation hypotheses. Literacy rates among rural males also have a significant positive impact on tubewell density, consistent with expectations that more educated farmers are more likely to understand the advantages of tubewell irrigation, and more able to carry out the administrative procedures necessary for getting a tubewell and pumpset.

Most aspects of agricultural production cannot be included in this model because of problems with endogeneity. That is, the level of output, yields, and input use is likely to be influenced by the presence of tubewells. While these decisions may also, in turn, affect the adoption of tubewells, it is difficult to establish causality in a cross-sectional study. The proportion of area under rice is included because the sensitivity of rice to moisture stress is likely to create particular incentives for tubewell investment. This is borne out in the results of the model: percentage of rice has a strong positive relationship with tubewell density.

The dummy variables for NWFP and Sindh capture residual effects, such as differences in the culture and policy environment between provinces. While NWFP was not found to differ significantly from the Punjab in patterns of tubewell density, Sindh had significantly lower density of tubewells after controlling for all other factors.

### INTENSITY OF WATER MARKETS

The density of tubewells predicted in the first model was used as an instrumental variable in a similar linear regression model for intensity of water market activity. Results of this model are as follows:

$$\begin{aligned}
 \text{TWSALES} = & -52.166^* - 0.047 \text{RAIN}^{**} + 1.003 \text{GWQUAL}^* - 0.026 \text{DEPTH}_A \\
 & (25.805) \quad (0.012) \quad (0.519) \quad (0.187) \\
 & + 10.475 \text{CANAL}^{**} + 0.192 \text{TWDENSE}_P + 0.331 \text{TOWN}_{10\_25}^* \\
 & (4.524) \quad (0.246) \quad (0.164) \\
 & + 9.045 \text{FRAGMENT} + 0.806 \text{LITERACY} + 27.908 \text{NWFP}^{**} \\
 & (5.035) \quad (0.542) \quad (13.389) \\
 & - 24.177 \text{SINDH}^{**} \\
 & (7.029)
 \end{aligned}$$

Adjusted R Square = 0.55,      Number of Observations = 30.

All variables are defined as in the first model, with the following additions:

**TWSALES** = Percent of tubewell owners selling water.

**DEPTH<sub>A</sub>** = Depth of groundwater after tubewell installation, in feet.

**TWDENSE<sub>P</sub>** = Tubewell density predicted in the first stage model, above.

**TOWN<sub>10\_25</sub>** = Percent of tubewell owners with land ownership 10 to 25 acres.

Instead of mean land ownership for all farmers, this model uses the proportion of tubewell owners in the 10 to 25 acre land ownership category. Characteristics of the tubewell owners has a larger bearing on their decisions of whether or not to sell water than does than the population of farmers at large (particularly once tubewell density is accounted for). Tubewell owners with medium-sized farms (10 to 25 acres) are most likely to have surplus water available for sale, while large farmers with over 25 acres are more likely to use all the water on their own lands, and a low proportion of farmers with less than 10 acres own tubewells.

Rural population density and proportion of area under rice are not included because they are expected to have less impact on water sales than on tubewell

density.<sup>4</sup> Although rice cultivation increases demand for tubewells, it limits both the supply and demand for groundwater sales. Tubewell owners growing rice use more of the water themselves, and therefore have less surplus to sell. Moreover, the unreliability of water through groundwater markets Meinzen-Dick and Sullins (1993) makes farmers reluctant to rely on water purchases for this water-sensitive crop, and prefer owning their own tubewells.

Rainfall is found to have a significant negative effect on groundwater sales, presumably because with higher rainfall there is less demand for groundwater. Unlike in the first model, poor quality groundwater has a significant positive effect on water sales. If much of the area has poor quality groundwater, farmers will seek to buy water from those with functioning tubewells (often in pockets of better-quality groundwater) rather than investing in their own tubewells where they are likely to have water quality problems. Depth of water table does not have a significant effect on water sales.

Canal irrigation has a strong positive effect on groundwater sales. This is likely to operate through both the supply and demand sides. In areas with canal irrigation there is more recharge and tubewell owners are less likely to need all the available water for their own crops, hence have more available for sale. On the demand side, inadequacies in canal deliveries create demand for supplemental groundwater. Furthermore, the watercourses used to supply canal water provide ready infrastructure for groundwater deliveries over a wider area, thereby facilitating water market transfers see Strosser and Meinzen-Dick (1993). Predicted tubewell density from the first stage of the model was used as an instrumental variable, but did not have a significant effect on water sales.<sup>5</sup>

The proportion of tubewell owners who own 10 to 25 acres has a significant positive effect on the proportion of tubewell owners who sell water. These medium-sized farmers are more likely to have excess water available for sale than will large farmers, who can use more of their tubewell capacity on their own land. Neither degree of fragmentation nor rural literacy rates have a significant effect on groundwater market activity. Tubewell owners in NWFP are more significantly likely than those in Punjab to sell water, while those in Sindh are significantly less likely. This may, in part, be due to differences in culture and commercial orientation between the provinces.

<sup>4</sup>In an alternative specification of the model, these variables were tested and found not to be significant. They were dropped from the final model to increase degrees of freedom and reduce multicollinearity with other variables.

<sup>5</sup>Actual tubewell density gave similar, non-significant results.

Rainfall, groundwater quality, canal irrigation, and farm size of tubewell owners clearly affect the proportion of tubewell owners who sell groundwater. However, a more complete understanding of the activity of groundwater markets would require addressing also the total amount and proportion of groundwater sold see Strosser and Kuper (1994).

## CONCLUSIONS AND POLICY IMPLICATIONS

To some extent private tubewell density and water market activity are substitutes for each other, with water market sales less necessary as a higher proportion of farmers own tubewells. However, the analysis in this paper indicates that different factors affect each type of groundwater irrigation development. Environmental problems of poor quality groundwater and falling water tables decrease the density of private tubewells, while a higher proportion of poor quality groundwater significantly increases the proportion of tubewell owners participating in groundwater sales (among those tubewells which are operating). The extent of canal irrigation and the proportion of tubewell owners with medium-sized land holdings have a significant positive impact only on tubewell water sales. On the other hand, rural development characteristics of population density and literacy had a positive impact on tubewell density, but not on water sales.

There is an explicit policy of promoting private tubewell development in Pakistan, particularly since the closure of public tubewells. However, there is presently no formal policy regarding water market development in Pakistan. In view of the large number of farmers, particularly smaller farmers, who depend on groundwater purchases to increase their agricultural productivity, the operation of groundwater markets merits further attention.

The appropriate objectives and policy instruments for dealing with the development of both private tubewells and groundwater markets depend on the local environment, particularly the extent of recharge and groundwater quality see Strosser and Meinen-Dick (1993). Because tubewell owners generally receive more reliable service and have higher returns than water purchasers, making tubewell ownership available to as many farmers as possible is advantageous if there are no groundwater constraints. However, if water tables are falling or of poor quality, stimulating further tubewell density is not sustainable. In such situations promoting private groundwater markets is particularly valuable to spread groundwater to as many farmers as possible.

This analysis indicates that the most direct policy instruments for encouraging water market development is targeting medium-sized farmers for tubewell

ownership. Well owners with 10 to 25 acres are more likely than larger farmers to have surplus water available for sale, and are more likely to provide reliable service to water purchasers. Directing credit and technical assistance for tubewell installation toward farmers in this size range will foster the development of groundwater markets and improve the equity of access to valuable groundwater resources.

While this study identifies determinants of groundwater market development at a national level in Pakistan, it leaves many questions unanswered. Using district-level statistics glosses over many micro-level variations which are likely to be important. Other factors (notably rural electrification) are omitted because of unavailability of data. Most importantly, it does not capture the dynamics of groundwater development. The NESPAK study provides an important baseline on the extent of private tubewell use, including water market activity. Follow-up studies could provide valuable time series information on how these changes over time, and the relationship to changes in the resource base, particularly groundwater quality and depth.

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